PERSPECTIVES ON HOW CV AV TECHNOLOGIES AND THE MUTCD

- US DOT – Eric Ferron, FHWA MUTCD Team
- State DOT – Peter Kozinski, Colorado DOT
- Research – Steve Shladover, Berkley
- OEM – Ed Bradley, Toyota
- Technology – Tammy Russell, 3M
- QnA

U.S. Department of Transportation
Federal Highway Administration

Connected Vehicles and Traffic Control Devices

Eric Ferron
FHWA Resource Center Operations Technical Service Team
NCUTCD Meeting – January 5, 2017

Agenda

- Fundamental Idea
- Goals
- Key Strategic Challenges
- MUTCD
- Potential Applications

Fundamental Idea

The power of wireless connectivity to bring about transformative changes in highway safety, mobility, and the environmental impacts of the transportation system.

- **Among vehicles (referred to as vehicle-to-vehicle or V2V communications),**
- **With the infrastructure (vehicle-to-infrastructure or V2I communications), and**
- **Mobile devices**

Goals

- Reduce highway crashes
- Improve mobility
- Enhance transportation system management and operations
- Reduce environmental impacts

Key Strategic Challenges

- To resolve remaining technical, policy, institutional, and funding challenges;
- To conduct testing to determine the actual benefits of applications;
- To determine whether overall benefits are sufficient to warrant implementation, and, if so, how the systems would be implemented; and
- To address issues of public acceptance such as maintaining user privacy and whether systems in vehicles are effective, safe, and easy to use.

MUTCD

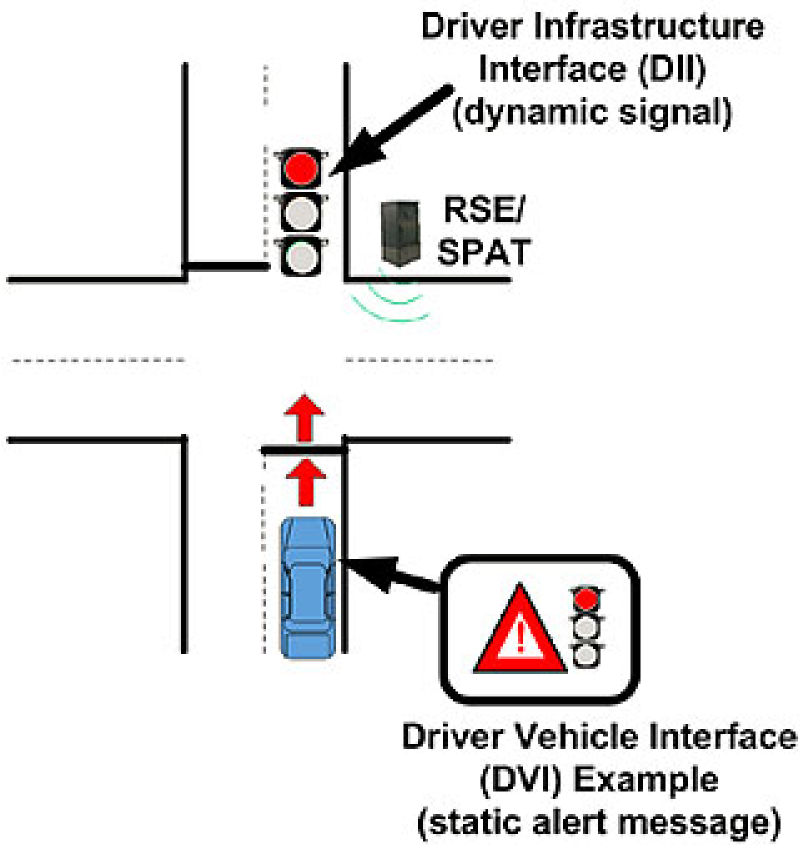
- What constitutes a traffic control device?
- Has CV changed the definition of TCDs?
- How do we maintain uniformity?
  - V2V
  - V2I
  - Existing TCD's
  - New Applications of TCD's

Potential Applications

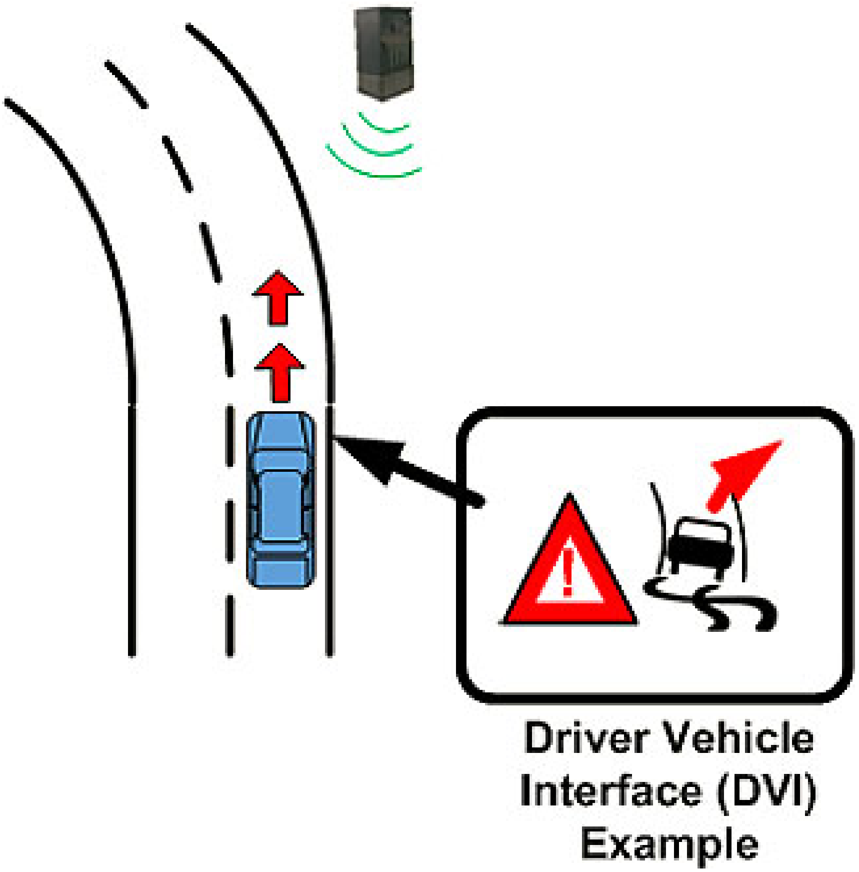
- Red Light Running
- Curve Speed Warning
- Stop Sign Gap Assist
- Railroad Crossing Violation
- Spot Weather Warning
- Oversized Vehicle
- Work Zone

Red Light Warning

- Broadcast between an RSE and OBE to determine if the vehicle is in danger of violating a red light
- Warn driver
- Extend all-red phase



Curve Speed Warning

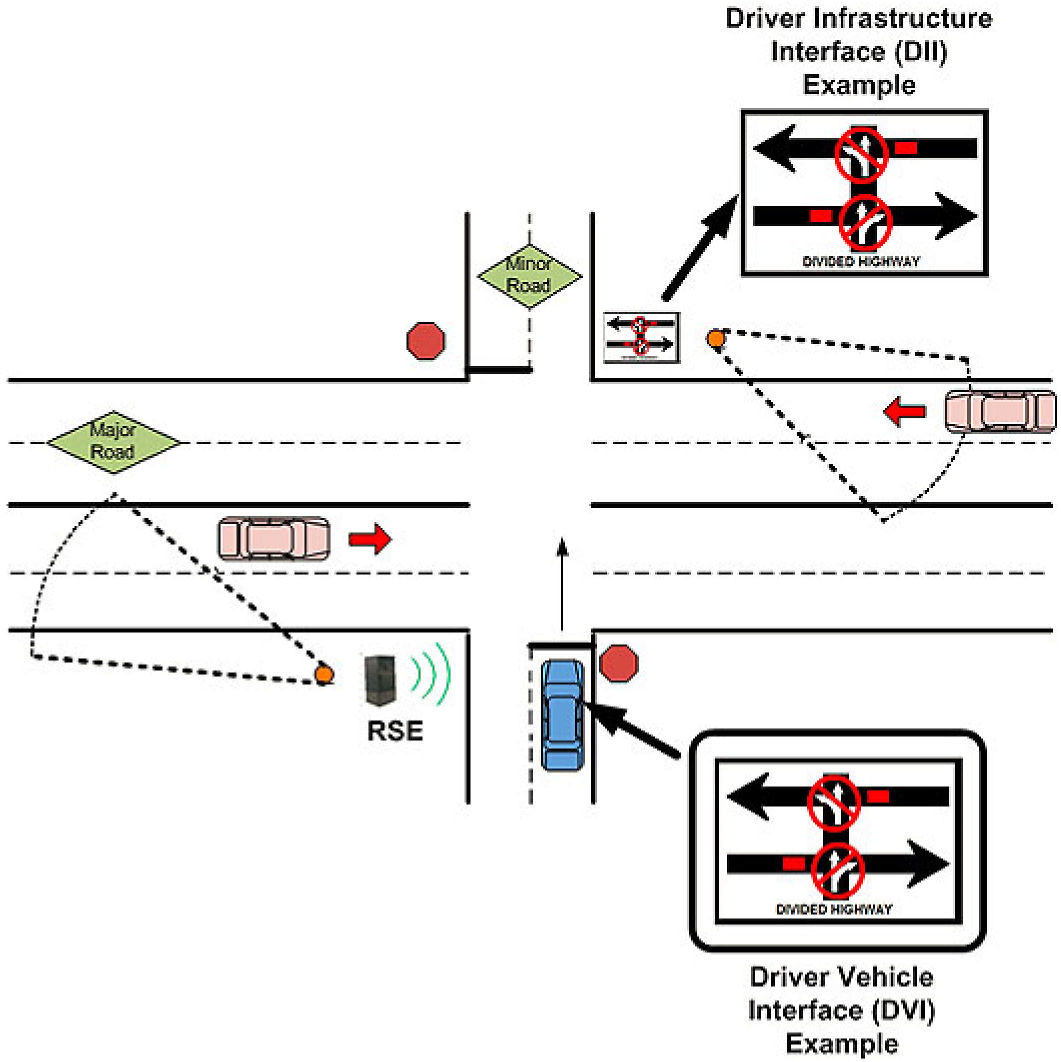


- Uses geometric and weather information
- Determines the appropriate speed
- Warnings can be tailored to the specific vehicle characteristics

U.S. Department of Transportation
Federal Highway Administration

Stop Sign Gap Assist

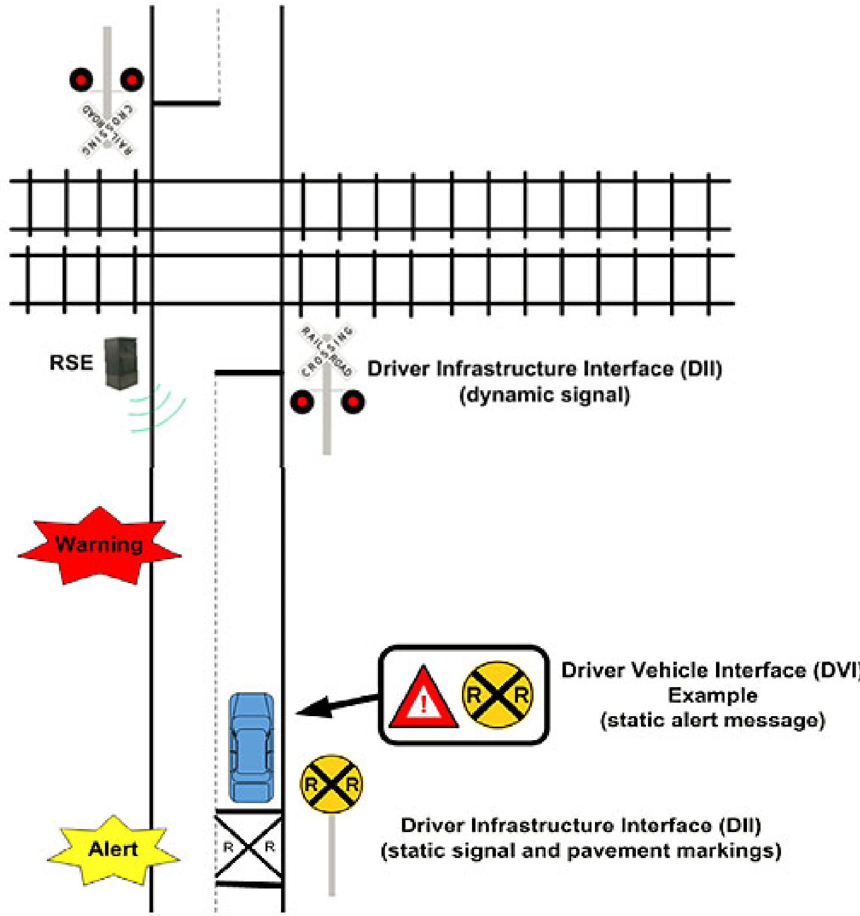
- Uses roadside sensors to detect oncoming traffic
- RSE broadcast traffic status



U.S. Department of Transportation
Federal Highway Administration

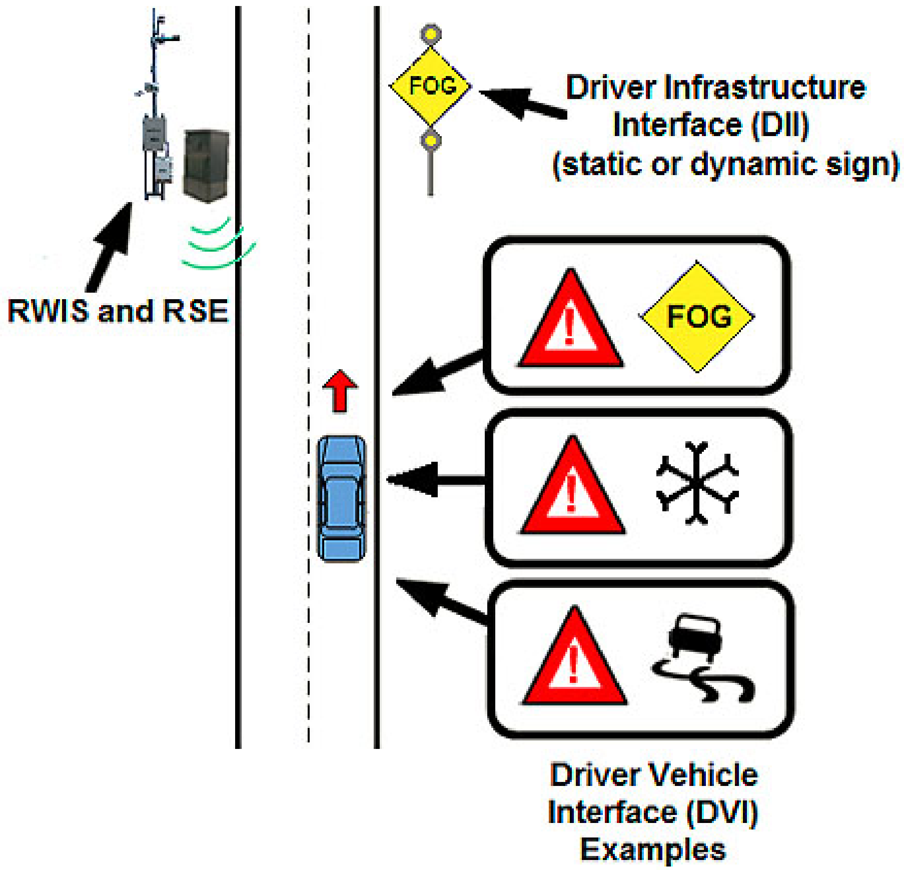
Railroad Crossing Violation Warning

- Uses roadside equipment to provide a connection to determine the probability of a vehicle conflict
- Issues an alert or warning to the driver



US Department of Transportation
Federal Highway Administration

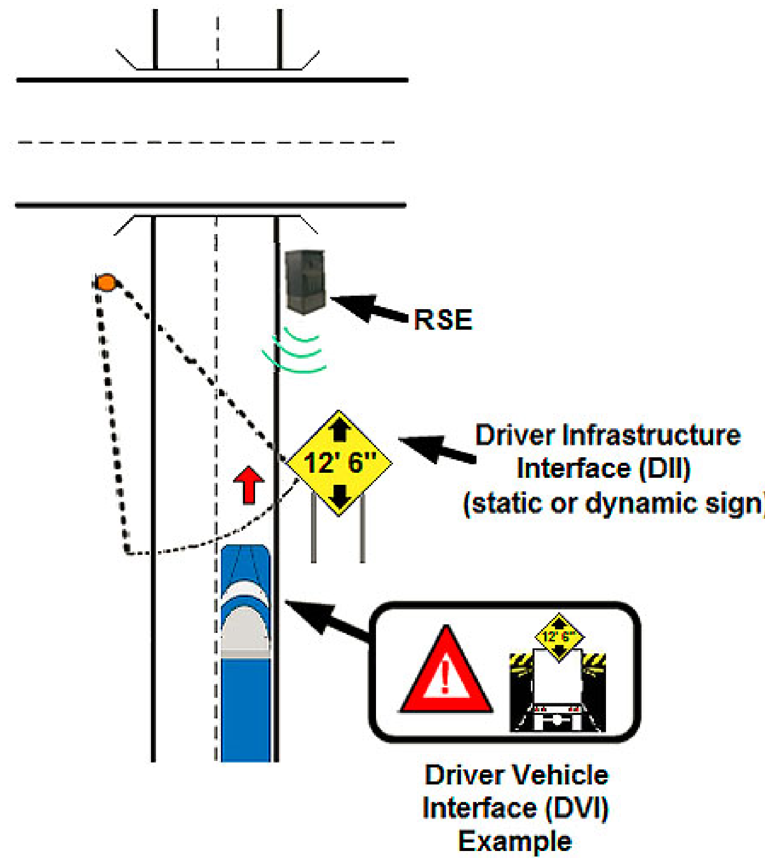
Spot Weather Impact Warning



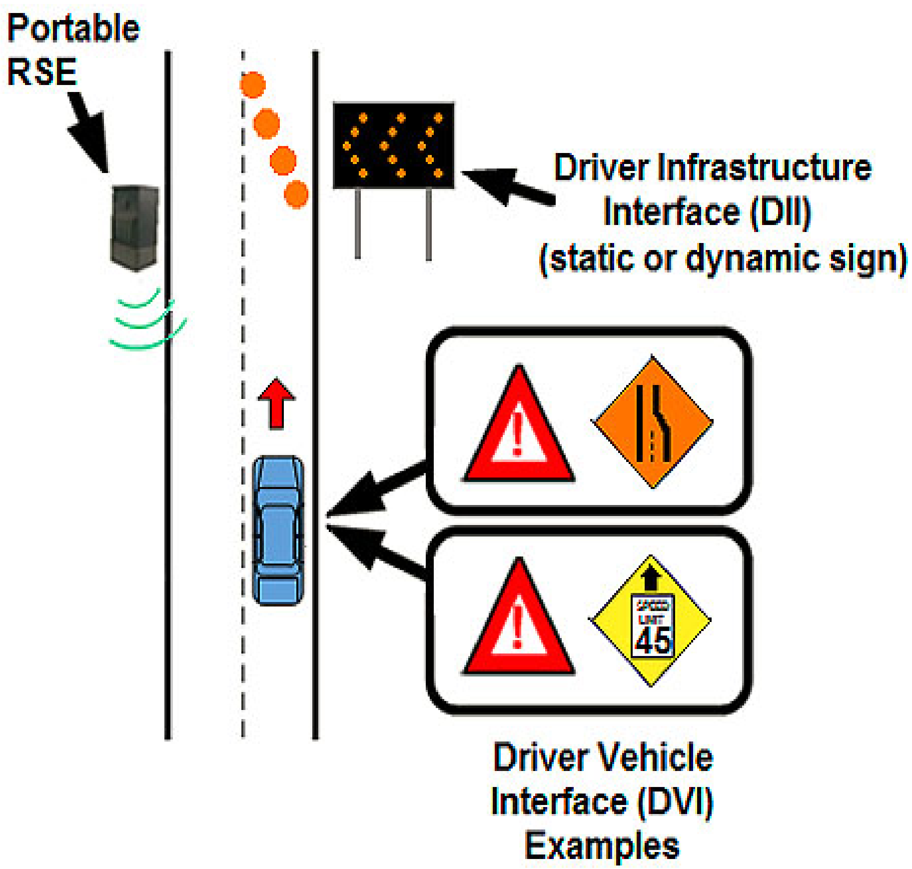
- Uses a connection from a traffic management center (TMC) and other weather data collection sites
- Issues real-time alert or warning to the driver

Oversize Vehicle Warning

- Uses a connection from an RSE to infrastructure-based detectors
- Either issues an alert to the driver to take an alternate route or provides a warning to stop



Reduced Speed or Work Zone Warning



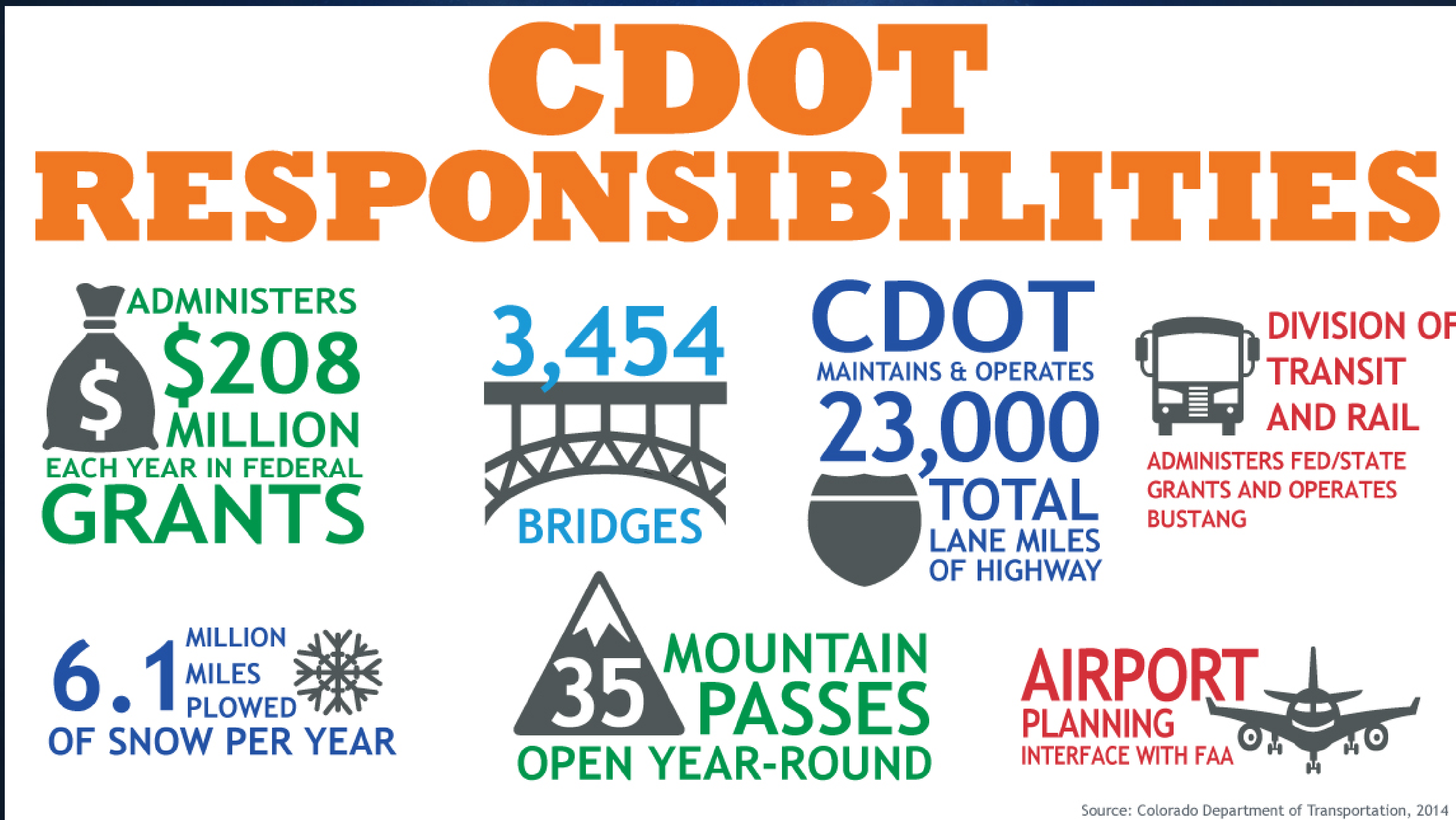
- Uses an RSE connection to broadcast speed limit and/or work zone information
- Alert the driver to reduce speed, change lanes, or prepare to stop

Questions?

COLORADO
Department of Transportation

MUTCD Meeting
January 5, 2017

FY 2016-2017
$1.44 Billion Budget



OUR CHALLENGE
Continued Growth

1991	2015	2040
3.3 million	5.4 million	7.8 million
27.7 billion vehicles miles traveled	**50.5 billion vehicle miles traveled**	**72.3 billion vehicle miles traveled**
\$ \$ \$ \$\$\$	\$ \$\$\$\$\$\$\$\$\$\$\$\$\$\$	\$
\$125.70 spent per person	\$68.94 spent per person	\$41.16 spent per person

All dollar figures adjusted for inflation

CDOT | ROAD X

Transportation Impacts Us All

- Vision for the Future
- Safety & Reliability
- Economic Vitality
- Rapid Technological Advancement
- Funding

WHY ACCELERATE TECHNOLOGY?

Safety
80% of accidents could be reduced or eliminated

Innovative Road Solutions
Could nearly quadruple highway capacity

Saved Time
Could save about 50 minutes per day

Expanded Mobility
Mobilizes elderly and handicapped populations

Environmental Benefits
Reduces congestion and vehicle emissions

ROADX

RoadX **VISION**: Crash-free, Injury-free, Delay-free and Technologically-transformed travel in Colorado.

RoadX **MISSION**: Team with public and industry partners to make Colorado one of the most technologically advanced transportation systems in the nation, and a leader in safety and reliability.

Colorado Is Open For Business – Colorado invites partners to join us in accelerating the adoption and deployment of technological solutions.

2016 2017 2018 2019


CDOT
CO
ROAD X
COMMUTING
SUSTAINABILITY
TRANSPORT
SAFETY
CONNECTION

TRANSPORT | TIMING : FALL 2016

Colorado partnered with Otto of Uber to complete the world's first commercial delivery by a self-driving truck. This approximately 120-mile demonstration of self-driving technology in the real-world environment of Colorado is a monumental next step in advancing safety solutions that will help Colorado move towards zero deaths on our roadways. Colorado is enthusiastic about working with Otto and others on:

- The long-term impacts and benefits of safely deploying this technology to enhance safety
- Improve environmental impacts of highway freight
- Foster the economic benefits advanced driving technologies are poised to bring to freight delivery and our state.

2016 2017 2018 2019

OTTO

CDOT | ROAD X

CDOT | ROAD X

NEXT STEPS

Privacy
Address security issues

People
Educate public

Technology & Planning
Plan and model for rapid change

ROI
Invest now in technology platforms

Regulation
Establish consistent policy direction that supports autonomous future

Questions?

Implications of Automation of Road Transport for MUTCD

Steven E. Shladover, Sc.D.

California PATH Program

University of California, Berkeley

NCUTCD Meeting, January 5, 2017

CALIFORNIA PATH

Outline

- **Diverse levels of road transport automation, with very different capabilities**
- **Timing for market introduction and growth**
- **Diverse technological approaches for automated vehicles acquiring knowledge of road environment**
- **Implications for infrastructure standards and regulations**

Operational Design Domain (ODD)

- **The specific conditions under which a given driving automation system … is designed to function, including, ...**
  - Roadway type
  - Traffic conditions and speed range
  - Geographic location (boundaries)
  - Weather and lighting conditions
  - Availability of necessary supporting infrastructure features
  - Condition of pavement markings and signage
  - (and more…)

CALIFORNIA PATH

Taxonomy of Levels of Automation
(SAE J3016 - http://standards.sae.org/j3016_201609/)

Driving automation systems **are categorized into levels based on:**

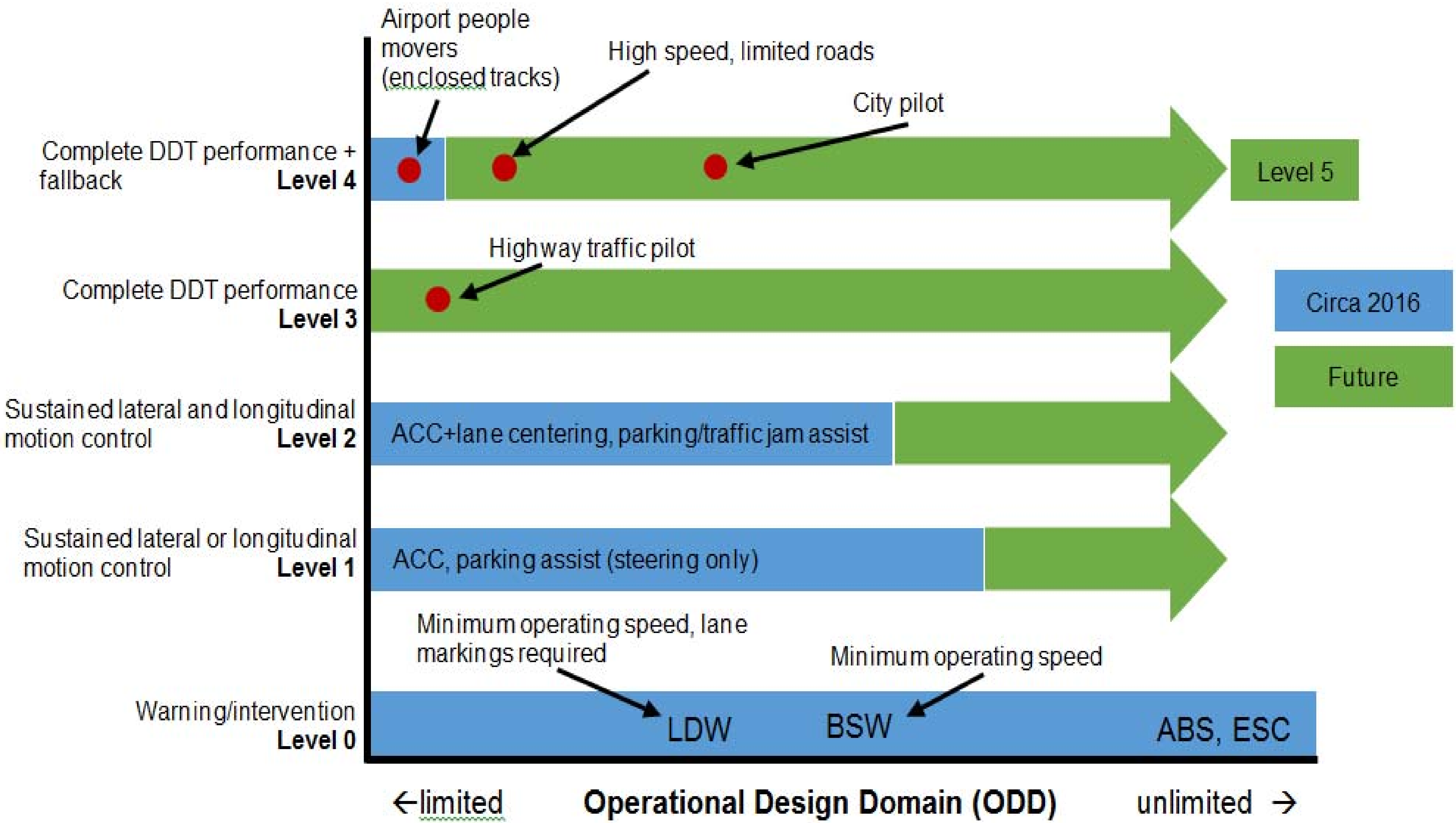
1. **Whether the driving automation system performs *either* the longitudinal *or* the lateral vehicle motion control subtask of the *dynamic driving task* (DDT).**
2. **Whether the driving automation system performs *both* the longitudinal and the lateral vehicle motion control subtasks of the DDT simultaneously.**
3. **Whether the driving automation system *also* performs *object and event detection and response*.**
4. **Whether the driving automation system *also* performs *DDT fallback*.**
5. **Whether the driving automation system is limited by an ODD.**

Level	Name	Narrative definition	*DDT*: *Sustained lateral and longitudinal vehicle motion control*	*DDT*: *OEDR*	*DDT fallback*	*ODD*
Driver **performs part or all of the *DDT***						
0	**No Driving Automation**	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	**Driver Assistance**	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	**Partial Driving Automation**	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
ADS **(“*System*”) performs the entire *DDT* (while engaged*)***						
3	**Conditional Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	**High Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	**Full Driving Automation**	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

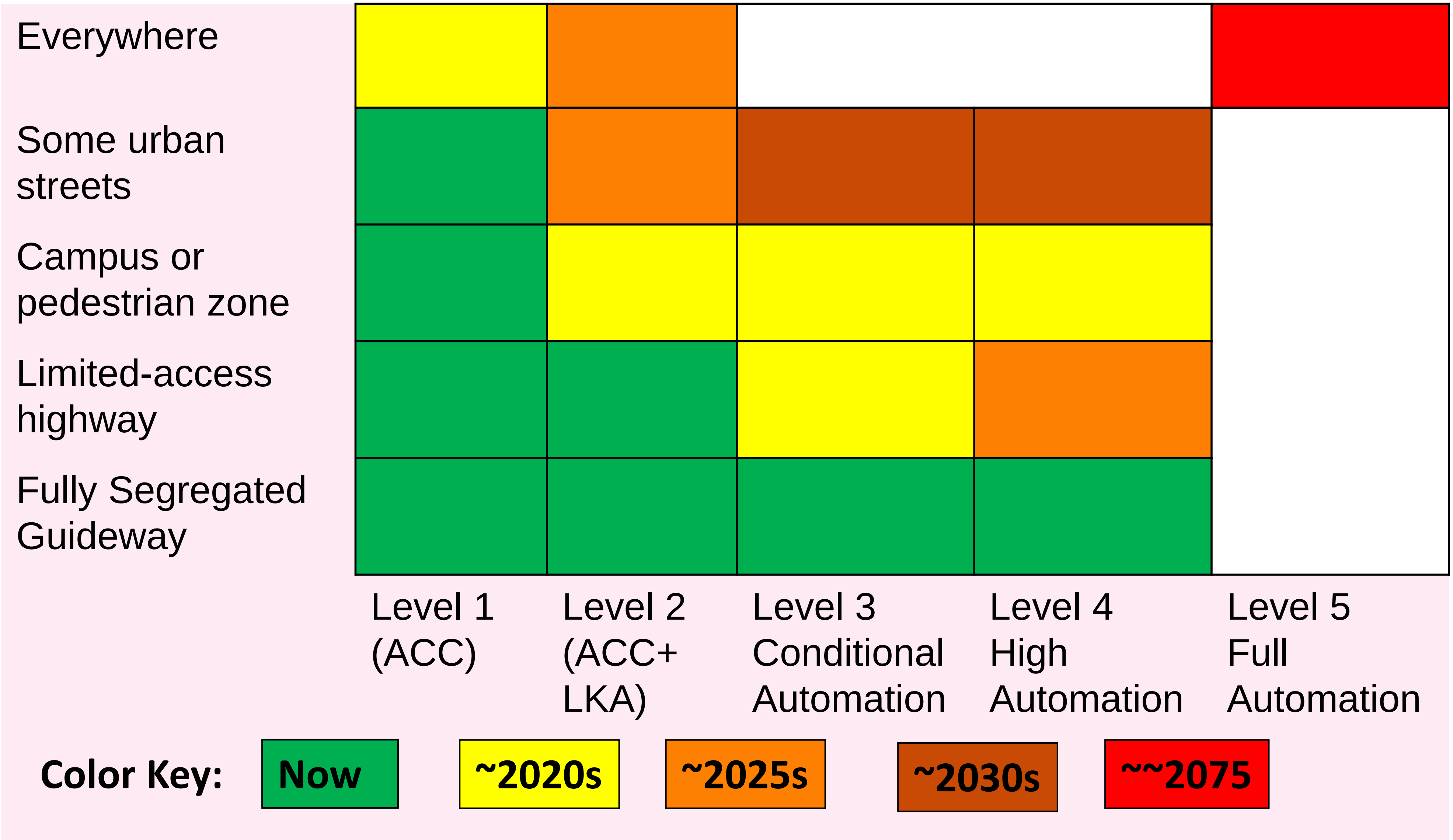
Example Systems at Each Automation Level

Level	Example Systems	Driver Roles
1	Adaptive Cruise Control OR Lane Keeping Assistance	Must drive <u>other</u> function and monitor driving environment
2	Adaptive Cruise Control AND Lane Keeping Assistance Traffic Jam Assist (Mercedes, Tesla, Infiniti, Volvo…) Parking with external supervision	Must monitor driving environment (system nags driver to try to ensure it)
3	Traffic Jam Pilot	May read a book, text, or web surf, but be prepared to intervene when needed
4	Highway driving pilot Closed campus “driverless” shuttle “Driverless” valet parking in garage	May sleep, and system can revert to minimum risk condition if needed
5	Ubiquitous automated taxi Ubiquitous car-share repositioning	No drivers needed

CALIFORNIA PATH


Airport people movers (enclosed tracks)
High speed, limited roads
City pilot
Complete DDT performance + fallback
Level 4
Level 5
Highway traffic pilot
Complete DDT performance
Level 3
Circa 2016
Future
Sustained lateral and longitudinal motion control
Level 2
ACC+lane centering, parking/traffic jam assist
Sustained lateral or longitudinal motion control
Level 1
ACC, parking assist (steering only)
Minimum operating speed, lane markings required
Minimum operating speed
Warning/intervention
Level 0
LDW
BSW
ABS, ESC
←limited
Operational Design Domain (ODD)
unlimited →

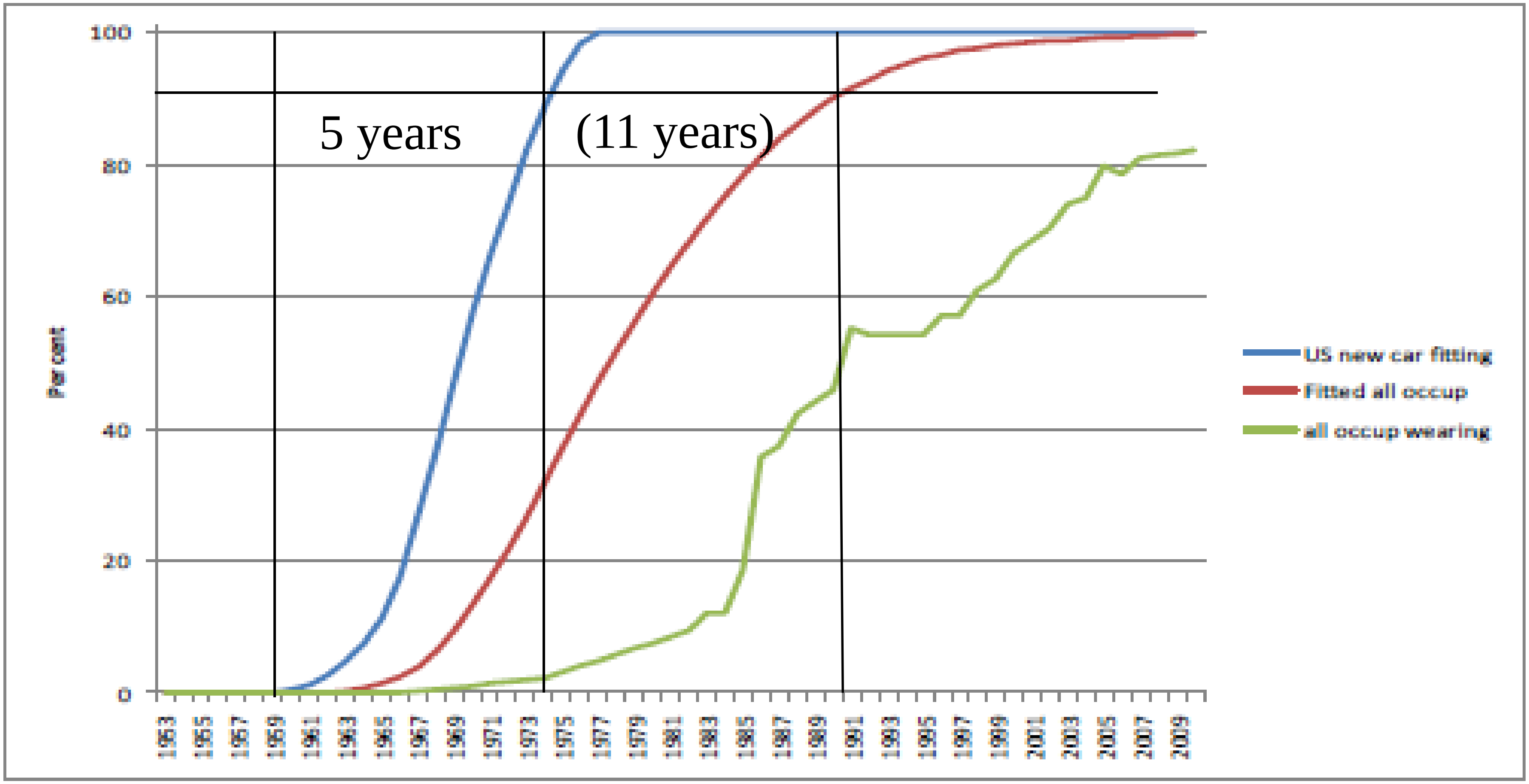
Personal Estimates of Market Introductions
** based on technological feasibility **



Example Market Growth for Seat Belts After Mandate

Figure 1: US seat belt adoption curves

Source: Gargett, Cregan and Cosgrove, Australian Transport Research Forum 2011



Fastest possible adoption, required by law in U.S.

PATH

Historical Market Growth Curves for Popular Automotive Features

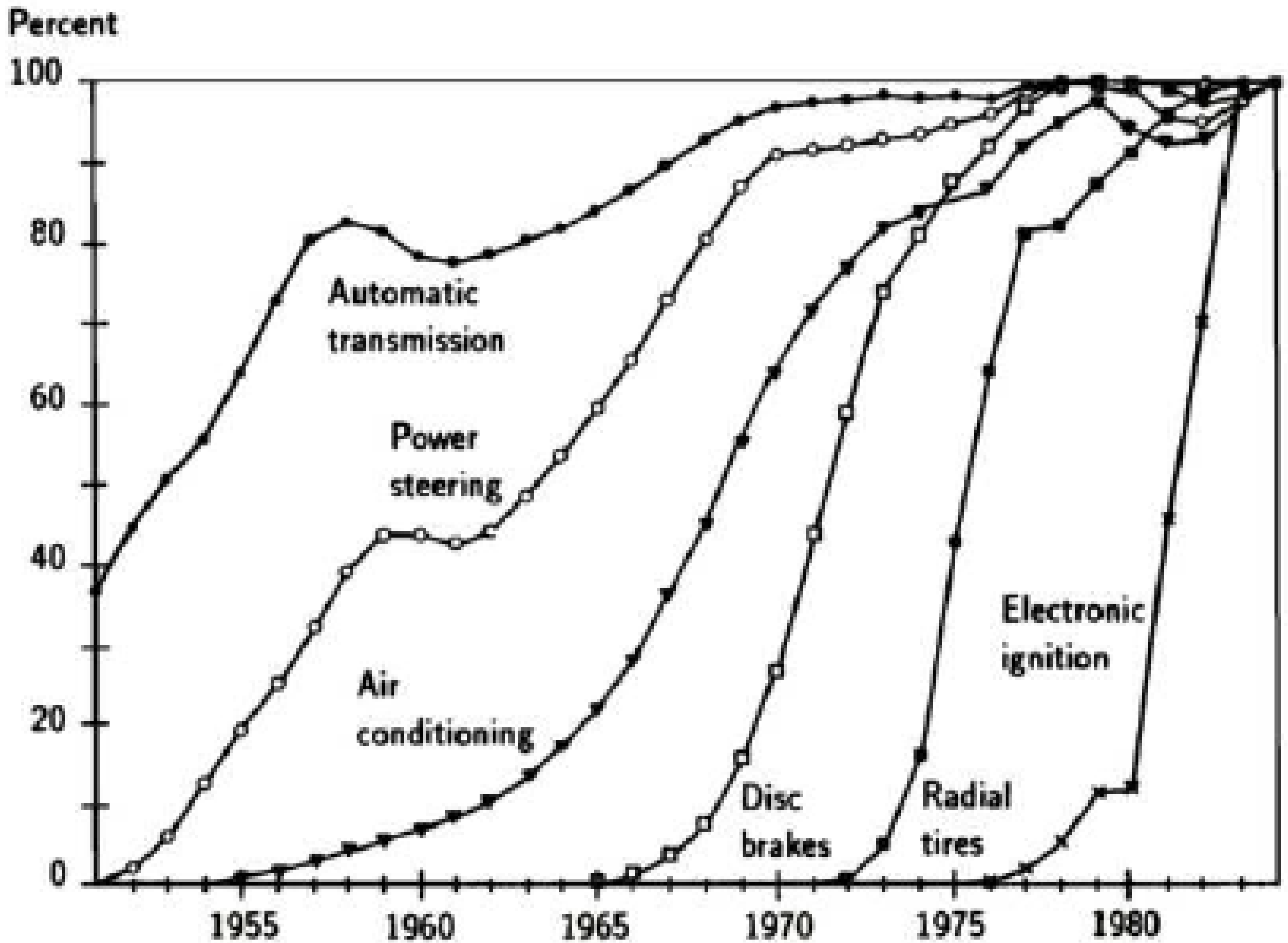


Figure 3.3.10. Diffusion of new technologies in the US car industry (in percent of car output). (Source: Jutila and Jutila, 1986.)

How can a vehicle automation system learn about the road environment?

- **Multiple approaches, which can be combined:**
  - **Digital map database of all relevant road features, combined with vehicle positioning using GPS/INS.**
  - **360 degree laser scanner(s) capturing reflections off all surrounding objects and matching them to a detailed database (SLAM)**
  - **Wireless communication devices on roadside downloading data to vehicles (DSRC, RFID)**
  - ***Optical sensors capturing visual and IR images of the driving scene and interpreting them***
  - **Radar sensors capturing RF reflections off objects in proximity**

CALIFORNIA PATH

Implications of optical sensing approach

- **Unlikely to be primary because of its vulnerabilities:**
  - **Loss of visibility in adverse weather (rain, snow, fog, dust,…)**
  - **Targets obscured by foliage, dirt or snow accumulations**
  - **Blinding at low sun angles or by glare**
  - **Confusion by shadows**
  - **Occlusion by other vehicles**
  - **Imprecision compared to other methods**
- **Probably useful to augment data from other methods**

Considerations for MUTCD

- **No big hurry!**
- **Anything that improves visibility for human drivers should help automation systems too**
  - **Human drivers will be the primary road users for <u>many</u> decades to come**
  - **Good maintenance of existing signs and pavement markings is most important**
- **Existing sensor systems have widely varying capabilities, but still worse than human eyes**
- ***** Don’t try to predict “winners” among sensing approaches, especially when technology changes rapidly *****

CALIFORNIA PATH

A Note on Planning Horizons

- **Common standards for vehicle optical sensors are unlikely – market competition will produce very diverse products at different price points**
- **Focus on needs of L1 and L2 driver assistance systems for the foreseeable future**
- **Remember differences in functional lifetimes of products:**
  - **Infrastructure: decades**
  - **Vehicles: years**
  - **Information technology: months**

Science.
Applied to Life.™

National Committee Meeting

Tammy Meehan
Global Portfolio Manager
Intelligent Transportation

Jan 5, 2017

3M Intelligent Transportation Materials Video

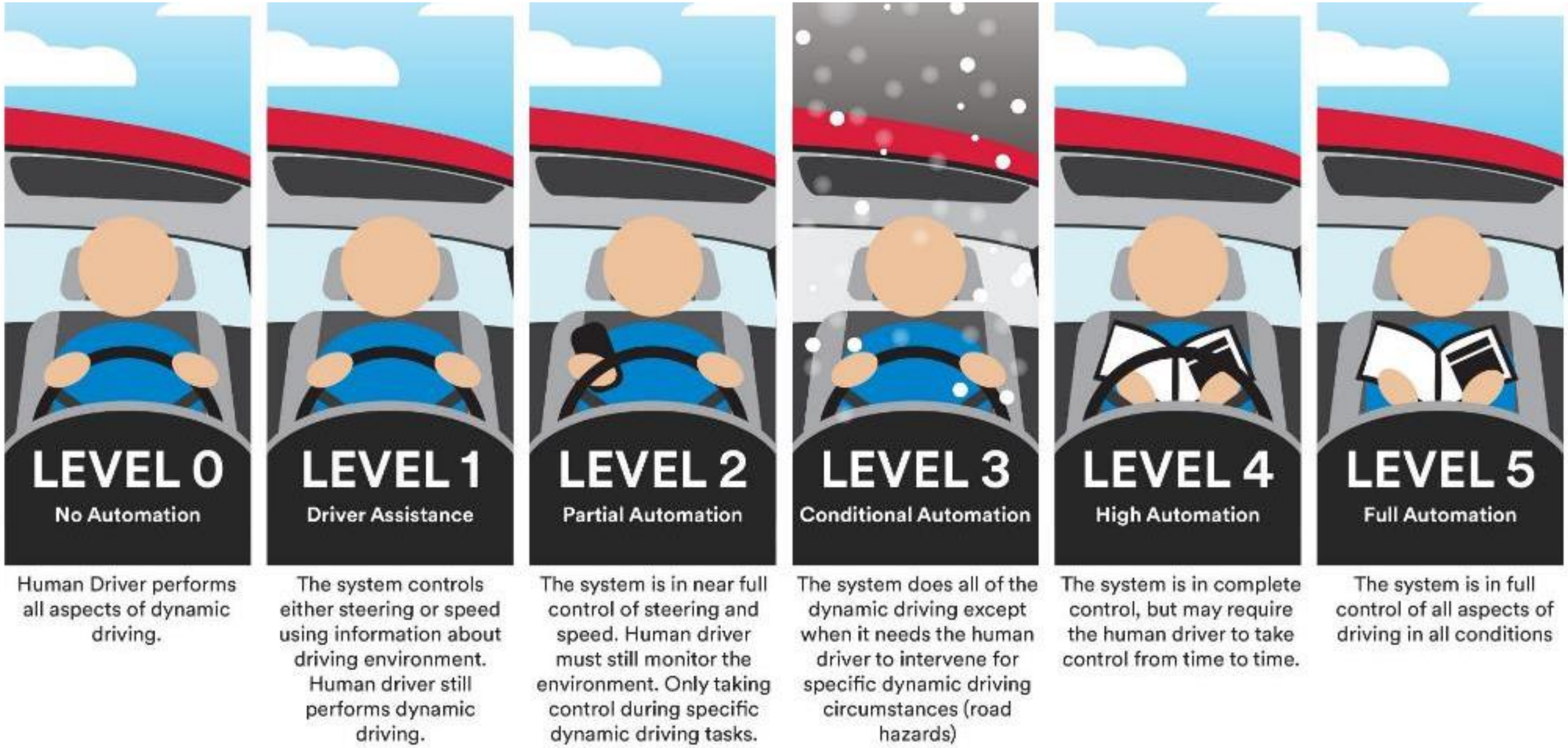
Automated Vehicles 101

- Levels of Automation
- The Ecosystem
- Highlight: The Vehicle

Ecosystem Engagements Key Themes

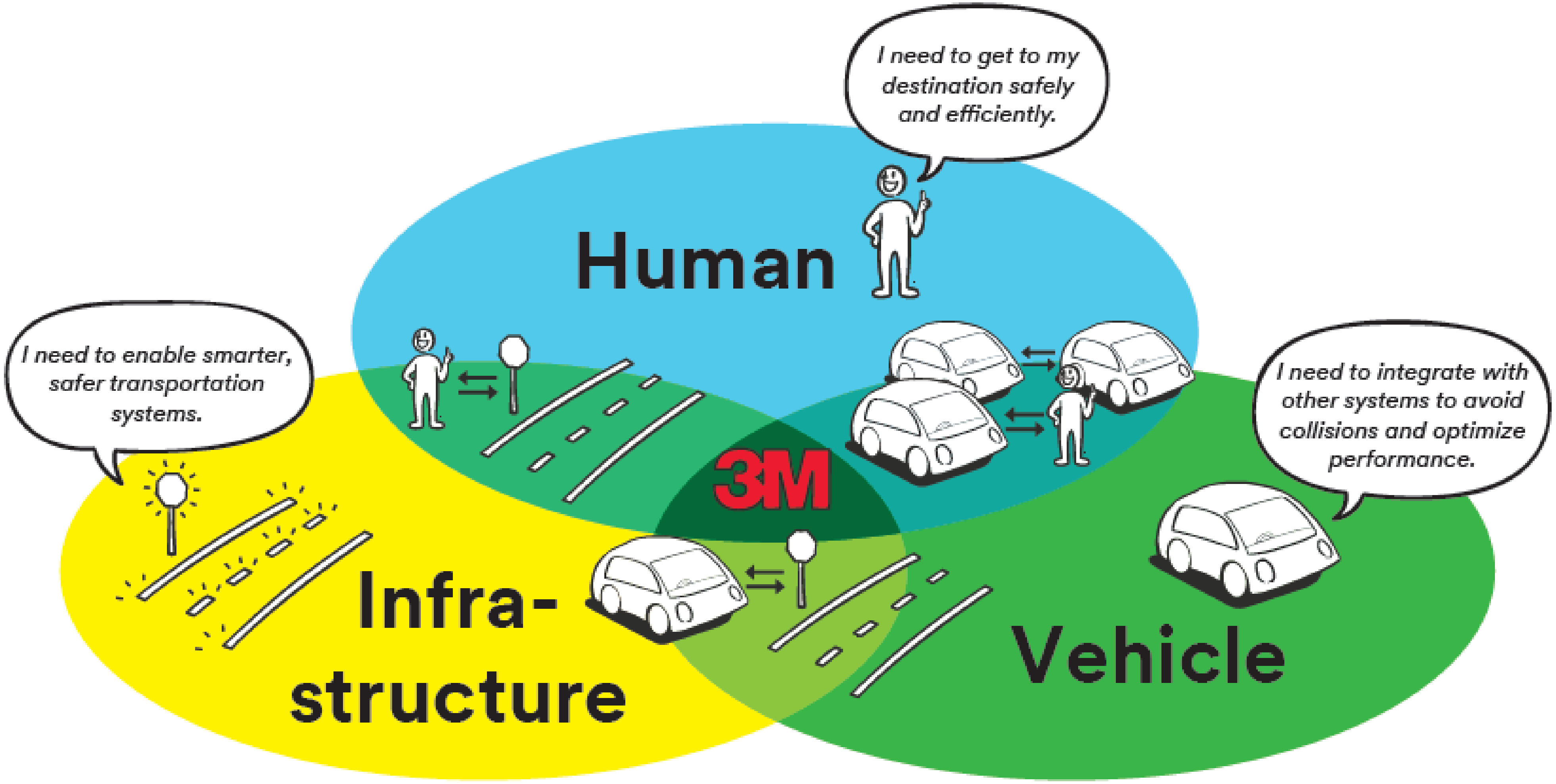
Levels of Automation – Automated Vehicles 101

SAE J3016



SAE Levels of Automated Driver Interactions

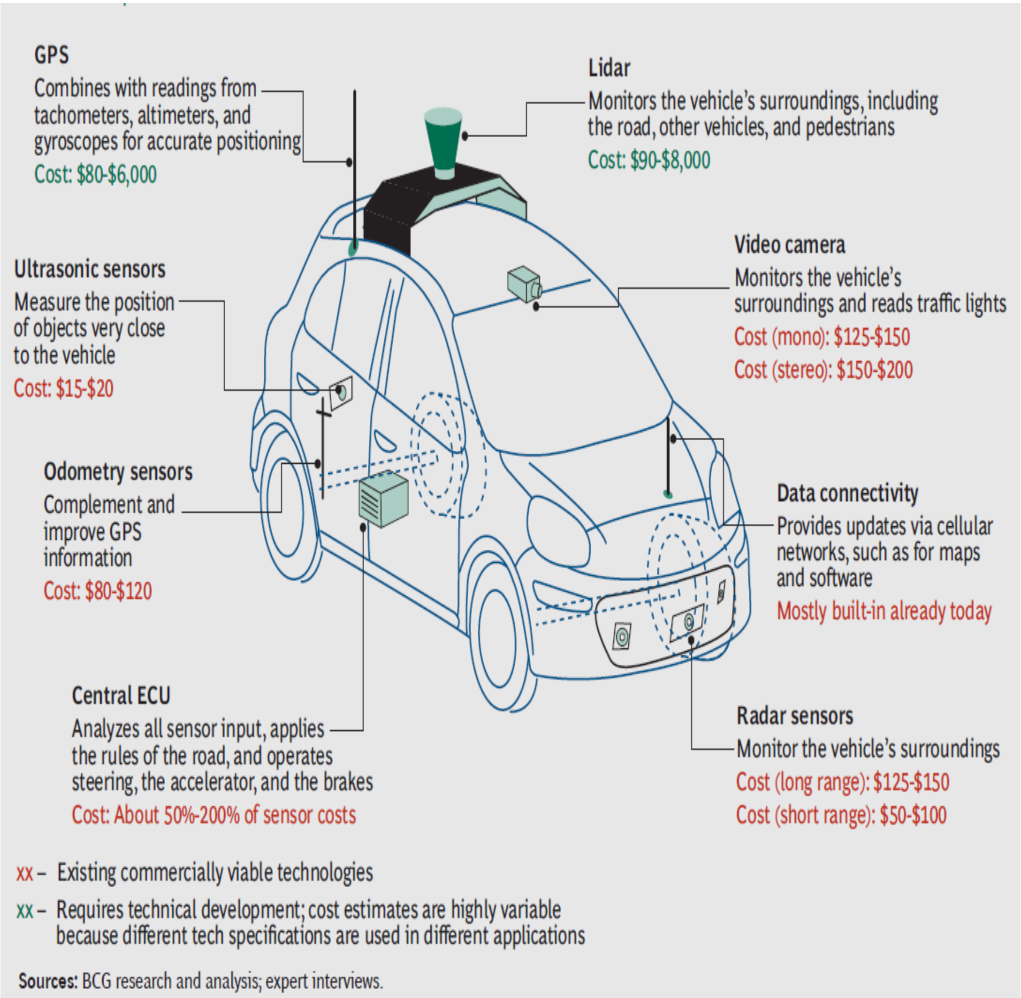
The Ecosystem



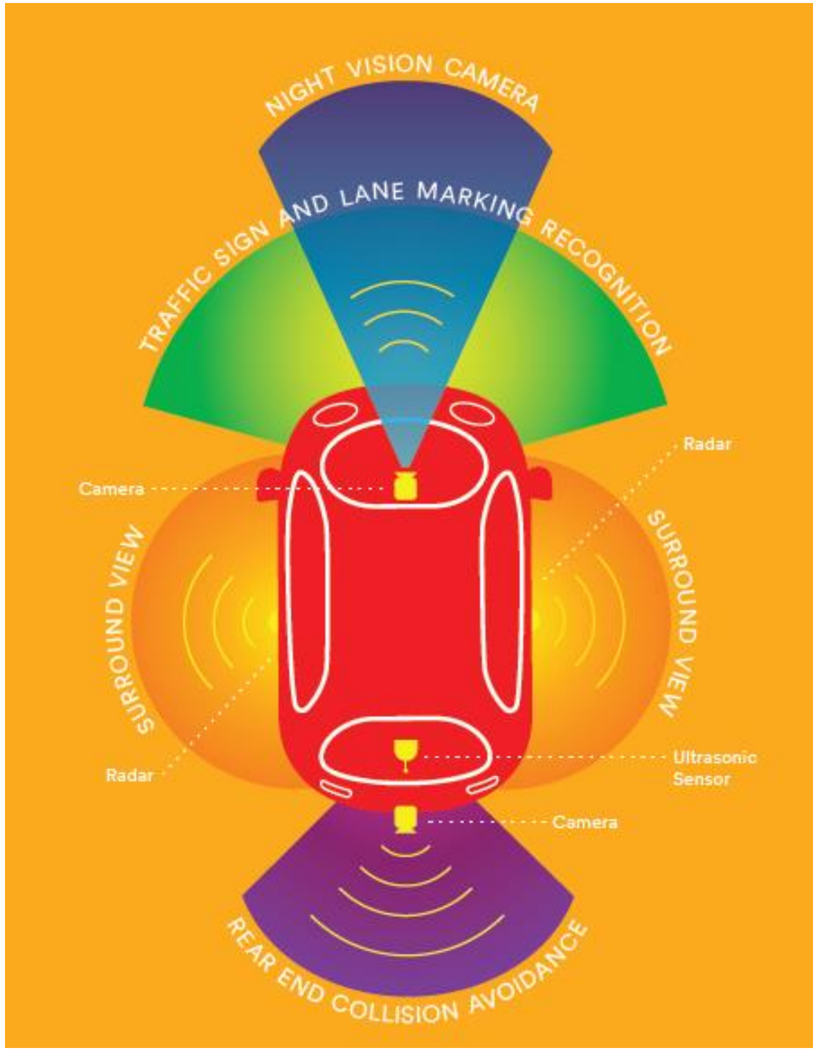
The Vehicle: From Human Vision to Machine Vision

Automated Vehicle features are comprised of many sensors and systems used to maneuver on the roads

Vehicle Sensors



Advanced Driver Assistance Systems



The Building Blocks of Autonomy

Prepared by VISION SYSTEMS INTELLIGENCE

+300 Engagements

Level of Integration

AUTONOMOUS SOLUTIONS

TOYOTA, TESLA, Ford, GM, HYUNDAI, KIA MOTORS, Google, UBER, NVIDIA, Continental, nauya, ZMP Robot of Everything, CHANGAN, HONDA, VOLVO, Mercedes-Benz, GEELY, Baidu 百度, VisLab Extend Your Vision, OTTO, nuTonomy, Audi, BMW, PSA PEUGEOT CITROËN, NISSAN, BAIC, SAIC, CHERY, DELPHI, BOSCH, RENESAS, drive.ai, ZOOX

PROCESSING

RENESAS, NVIDIA, MOBILEYE, NXP, TOSHIBA Leading Innovation, CEVA, cadence, Imagination, ARM, ANALOG DEVICES, intel, XILINX, videantis passion for video, ALTERA, Texas Instruments, MARVELL, QUALCOMM, Movidius, ST

SENSORS

BOSCH, DELPHI, MITSUBISHI ELECTRIC, Continental, ibeo, Valeo, HITACHI, Autoliv, TOSHIBA Leading Innovation, HYUNDAI MOBIS, POINT GREY Innovation in Imaging, Pioneer, KOSTAL, DENSO, LG, Panasonic, MAGNA, HARMAN, FUJITSU, Melexis Microelectronic Integrated Systems, Mando, OSRAM, applanix A TRIMBLE COMPANY, FLIR SYSTEMS, ON Semiconductor, LeddarTech, Neusoft, Infineon, SONY, PEPPERL+FUCHS, TRILUMINA, ublox, Velodyne LiDAR, PHANTOM INTELLIGENCE

CONNECTIVITY

HITACHI, RENESAS, Continental, NXP, BOSCH, DELPHI, intel, QNX, TTTech, DENSO, Infineon, HARMAN, Mentor Graphics

MAPPING

TomTom, here, Google, NAVINFO, mapscape, HARMAN, NVIDIA, GeoDigital, ZENRIN, applanix A TRIMBLE COMPANY, sanborn, Civil Maps, AND

ALGORITHMS

MOBILEYE, NVIDIA, MITSUBISHI ELECTRIC, Elektrobit, dSPACE, AdasWorks, Neusoft, ETAS, LUXOFT, KPIT, VECTOR

SECURITY/SAFETY

HITACHI, RENESAS, Mentor Graphics, BOSCH, Continental, DELPHI, NXP, WIND, ARGUS CYBER SECURITY, Elektrobit, intel, QNX, ETAS, DENSO, HARMAN, Green Hills SOFTWARE, Infineon, KPIT, VECTOR

DEVELOPMENT TOOLS

BASELABS, IAR SYSTEMS, LDRA, MathWorks, SYNOPSYS, VECTOR software, automotive engineering iav, Elektrobit, KPIT, LUXOFT, Mentor Graphics, HARBRICK, KISHONTI INFORMATICS, INTEMPORA MULTISENSOR SOFTWARE SOLUTIONS, tass international, TTTech, dSPACE, ETAS, VECTOR, QNX

Key Themes from the Ecosystem

Redundancy and **Simplification** (Standardization)

Intelligent Transportation Technology and Challenges

Applying science to solve challenges on the road to zero deaths

Level 1 – 3 Machine Vision

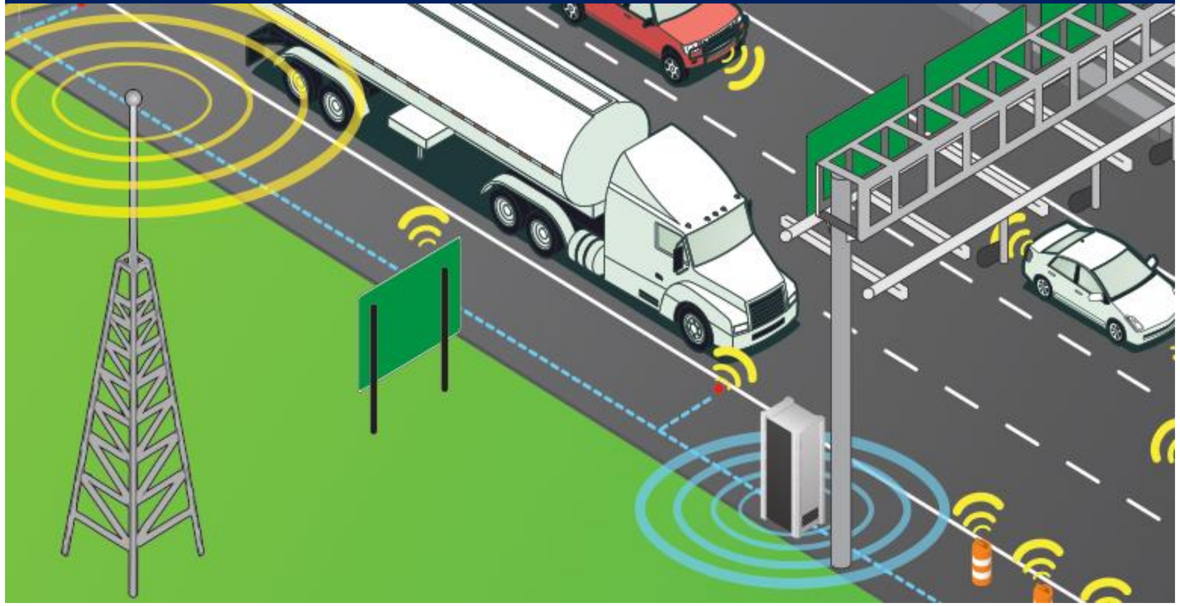
Technologies

- Vehicle sensors (visual, IR, sonic)
- Automatic braking
- Lane departure warning
- Adaptive cruise control
- Sign recognition

Challenges

- Human behavior/confidence
- Poor/inconsistent road markings
- Technology redundancy
- Inclement weather

Level 3 – 5 Connected Infrastructure



Technologies

- Vehicle-to-Vehicle
- Vehicle-to-Infrastructure (beacons)
- Vehicle-to-Cloud
- Big data analytics for traffic mgmt

Challenges

- Intersections, work zones, etc.
- Regulatory standardization
- Connectivity and bandwidth
- Inclement weather

Pavement Markings

"The number 1 issue with the DELPHI Drive across the U.S. was Pavement Marking Detection"

"If you could focus on just one thing it should be making clear and consistent lane markings for the automated vehicle systems"

"We need brighter and greater contrast pavement markings on all roads"

Construction Work Zones

"If you could move the Work Zone Ahead sign up by about 100 meters that could help give us enough notice to allow the driver to take over for Level 4 Automation"

"Work Zones need Connectivity in order to give the vehicles the real time information they'll need"

"Our most challenging Edge Cases are work zones and specifically how to confidently detect, classify and navigate within the Work zone"

RESEARCH & CV-AV MEETING

- Thursday, 6:00 PM to 7:30 PM
- Adams Room

RESEARCH

- Call to Order and Welcome (Carlson)
- Review problem statements submitted to NCHRP (Carlson)
  - Uniform Guidelines for LED signs
  - Design and Operation of Bicycle Signals
  - Understanding the Physical Highway Infrastructure Needs to Support AV Technologies
  - Signing for Restricted Sight Distance at Vertical Curves
  - Markings for Managed Lanes, Toll Plazas, and Active Travel and Demand Mgmt (ATDM) Operations.
- NCHRP Program Update (Derr)
  - Synthesis Studies Due Date: Feb 17, 2017
  - http://www.trb.org/Studies/Synthesis/SynthesesSubmittal.asp
- TRB 2017 AM Preview (Cunard)

CAV TASK FORCE

- Summary of Thursday Panel Presentations
- Technical Committee Input
- Upcoming Events
  - NCUTCD Mtg, Pittsburgh, PA
    - June 28-30, 2017
    - CMU Visit / Demonstrations
  - TRB Automated Vehicle Symposium, San Francisco, CA
    - July 11-13, 2017
    - http://www.automatedvehiclessymposium.org/home